

Research of the issues of frequency and time support of the GLONASS system

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Abstract. The article deals with the ways of improving the accuracy of comparison of time scales of frequency and time standards in differential mode as well as the methods and algorithms for the implementation of differential comparisons of time scales of the spatially spaced highly stable clock. The accuracy of the location depends on many factors. With the GLONASS fully deployed orbital structure, one of the main factors determining the accuracy of obtaining the consumer coordinates is the accuracy of the navigation information transmitted as part of the navigation frame. The navigation information accuracy is determined by the state of ephemeris-time support.

1. Introduction

Currently, the issues related to the use of navigation systems are widely studied [1-5]. When considering navigation systems, both hardware and software are studied [6-12]. It should be noted that most often the researchers distinguish two main systems: GLONASS and GPS [13-17]. This article discusses the impact of the frequency and time support on coordinates determination accuracy.

The global trends in the continuous expansion of satellite navigation applications, as well as various consumer advanced requirements for navigation services cause the increased requirements for acceptable errors in navigation and temporal definitions and, consequently, for errors in the ephemeris-time support of the global navigation system GLONASS.

The GLONASS and the GPS space navigation systems do not provide the accurate characteristics of the navigation field, which would satisfy advanced consumers. The implemented projects of modernization of these systems are mainly focused on improving the stability of the onboard frequency standards, improving the track measuring ground based system, on synchronizing the onboard frequency standards by the ground-based standard, on specification of moving model of the spacecrafts along the orbit.

The main limiting factor in improving the accuracy characteristics of the frequency and time support is the high level of instability of the GLONASS navigation spacecrafts existing onboard

standards based on cesium ray tube, which is the main source of errors in forecasting operational frequency-time corrections of navigation spacecrafts. With the provided characteristics of daily volatility σ at the level of 10^{-13} the forecasting error of frequency-time the adjustments for 12 hours (tab time-frequency corrections on navigation spacecraft board once at each turn) is set at 6 nanoseconds standard deviation. The in practice observed the value of prediction error of frequency-time corrections due to various kinds of disturbing factors exceeds the indicated value by 1.5...2 times.

2. Synchronization system of the onboard time scale of the navigation satellite

The frequency and time support is implemented by the GLONASS synchronization system, which provides the formation of a unified system time scale, the synchronization of onboard time scales of each of navigation satellite with the system time scale, the calculation of time-frequency corrections, the definition of the divergence of the system time scale relative to the scale of the State standard coordinated universal time UTS(SU), the corrections calculating of the onboard time scales relative to the system time scale, the tab amendments to the onboard navigation satellites (twice a day) to transfer them to consumers as part of the navigation message.

The synchronization system includes:

1. The cesium on-board time and frequency standard of the navigation system ensuring the formation and storage of the on-board time scale of the navigation system. The daily relative frequency instability is 5×10^{-13} for the GLONASS navigation system and 1×10^{-13} for the GLONASS-M navigation system. The accuracy of the mutual synchronization of the onboard time scales of the GLONASS navigation system is 20 nanoseconds, and of the GLONASS-M satellites is 8 nanoseconds.
2. The central synchronizer of the system, ensuring the formation of a system time scale using hydrogen frequency standards with daily frequency instability not worse than $1 \dots 5 \times 10^{-14}$ and relative frequency instability not worse than 1×10^{-13} . For the GPS system, these parameters have the values of 3×10^{-14} и 1×10^{-12} , respectively (for one of the stages of using the system).
3. The binding equipment that provides the divergence definition of the system time scale and the universal time scale UTS(SU), which should not exceed 1 milliseconds (1σ). The binding error of these scales should not exceed 1 microseconds (1σ).
4. The phase control system performing active and passive range measuring in all navigation systems and transferring the measurement results to the system control center for checking the onboard time scale with the system time scale.
5. The control stations providing monitoring and control of the onboard time scale and transferring the frequency-time parameters to the navigation system.
6. The software tools of the system control center calculators, providing the coordinated operation of the subsystems, the periodic determination of the deviation of the onboard time scales relative to the system time scale, the calculation and prediction of time-frequency parameters for the navigation system. This takes into account the influence of relativistic and gravitational effects on the formation of the onboard time scale.

The frequency-time corrections are calculated at each turn of the navigation system and are laid on board the navigation system twice a day. Frequency-time parameters are two parameters of linear approximation of the displacement of the onboard time scale relative to the system time scale, with the prediction error of the onboard time scale for 12 hours is an average of 14 nanoseconds. The GLONASS-M navigation system uses more stable cesium frequency standards, which provide a prediction error of the onboard time scale of 12 hours equal to 5 nanoseconds.

The GLONASS system time scale is adjusted simultaneously with the planned correction for an integer number of seconds of the Coordinated universal time scale (UTS). The UTC correction by ± 1 second is carried out by the International Bureau of time on the recommendation of the International Earth Rotation Service (IERS). The correction of the UTS scale is made, as a rule, with a periodicity of once a year (one and a half years) at the end of one quarter: at 00 h 00 min 00 sec from midnight from 31 December to 1 January – 1st quarter (or from 31 March to 1 April-2nd quarter, from 30 June

to 1 July – 3rd quarter, from 30 September to 1 October- 4th quarter) and is carried out simultaneously by all users reproducing or using the UTS scale.

Therefore, between the GLONASS system time scale and UTS (SU) there is no shift by an integer number of seconds. This reduces the information amount transmitted to the consumers by the discrepancy. between the system time scale and UTS(US). Between the GLONASS system time and UTC (SU) there is a constant shift by an integer number of hours, due to the peculiarities of the functioning of the monitoring and control subsystem:

$$t_{\text{UKJYFCC}} = \text{UTS}(\text{SU}) + 03 \text{ h } 00 \text{ min.}$$

In the future, it is expected to reduce the error of mutual synchronization of the phases of navigation system signals to 15 nanoseconds not in 24 hours, as well as to coordinate the GPS and GLONASS system time scales. The time scales matching is based on the high characteristics of the UTC(SU) scale.

The GLONASS-M satellites transmit two coefficients (B1 and B2) for the transition to the world time scale UT1 and the correction τ_{GPS} is not worse than 30 nanoseconds.

3. Onboard time scale error compensation

One of the essential components of the pseudo range determining errors are the errors of the onboard time scale. Partial compensation of these errors is carried out as a result of the accumulation of statistical data on fluctuations of the onboard reference generator, which is carried out by the groundbased monitoring and control segment.

As a result of such processing, estimates of the following parameters are formed:

- shift of the time scale of the n-th navigation system relative to system time scale τ_n ;
- relative deviation $\gamma_n = (f_n - f_{nn}) / f_{nn}$ of the predicted carrier frequency f_n of the n-th navigation system from the nominal value of this frequency for the same navigation system.

The values of the parameters τ_n , γ_n are transmitted by the ground control complex via the communication line to the board the navigation system, where they are put into the navigation message. This information is updated every 15 minutes; therefore, the notation $\tau_n(t_b)$, $\gamma_n(t_b)$ is used where t_b is the time within the current day on the UTC (SU) scale +03 h 00 min, which includes the transmitted parameter values. In the receiver, the correction to the onboard time scale can be calculated in accordance with the formula

$$\delta t_{\tilde{NO}}(t) = \tau_n(t_b) + \gamma_n(t_b)(t - t_b) \quad (1)$$

It should be noted that the predicted value of the carrier frequency f_n is given taking into account the gravitational and relativistic effects at the time t_b .

4. Analysis of factors affecting the calculation accuracy of the discrepancy of the time scale of the spacecraft relative to the ground based monitoring and control station

The error in determining the difference in the onboard time scale of the spacecraft on the basis of non-request and requested range measurements depends on the technical characteristics of the corresponding measuring instruments, the methodological error in processing the measurements of the current navigation parameters and the methodological error in determining the difference in the onboard time scale of the spacecraft.

The error in determining the discrepancy between the onboard time scale of the spacecraft on the basis of non-request measurements and calculated range values depends on the technical characteristics of the non-request meter of the ground monitoring and control station, the methodological error of processing and the error in determining the calculated range, which, first of

all, is determined by the coordinates accuracy of the spacecraft (ephemeris) and the coordinates of the ground monitoring and control station.

The analysis of the error components of synchronization of the spacecraft onboard time scale relative to the GLONASS system time scale shows that the error in the formation of the frequency-time parameters is largely determined by the error in determining the difference in the onboard time scale of the spacecraft at the time of measurements of technical means.

When implementing the request-and-nonrequest technology of time-frequency determination, the methodical error in determining the discrepancy of the spacecraft time scale is determined by:

- a) error of pseudo range code measurements;
- b) methodical error of processing nonrequest measurements including:
 - calculation of the ionospheric correction;
 - calculation of the tropospheric correction;
 - calculation of corrections due to removal of the antenna phase center of spacecraft;
 - calculation of corrections due to removal of the phase centers of receiving antennas;
 - accounting for delays in the transmitting track at each frequency;
 - accounting for delays in the receiving and measuring track of the ground monitoring and control station;
- c) methodical error of processing the requested range measurements, including:
 - calculation of the ionospheric correction at the radiation frequencies of the direct and response signals;
 - calculation of the tropospheric correction;
 - accounting for delays of direct and response signals in the onboard and ground equipment;
 - calculation of corrections due to the removal of the phase centers of the receiving and transmitting antennas of the spacecraft;
 - calculation of corrections due to the removal of the phase centers of the transmitting and receiving antennas of the ground-based request equipment;
- d) error of calculating the reduction corrections to bring the measurements of the request and non request range to a common reference point;
- e) error in determining single values of the divergence of the spacecraft's on-board time scale, taking into account the reduction of request and non request range measurements to synchronous time points;
- f) methodological error in determining the session value of the discrepancy of the spacecraft's on-board time scale when processing single values;
- g) error of bringing the session values of the discrepancy of the spacecraft's on-board time scale relative to the time scale of the ground monitoring and control station to the values of the spacecraft's on-board time scale discrepancy relative to the central station time base taking into account systematic and calibration corrections to the time scale of the ground monitoring and control station;
- h) error of bringing the session values of the discrepancy of the spacecraft time scale relative to the central station time scale to the values of spacecraft time scale relative to the system time scale.

When implementing the nonrequest technology of frequency-time support instead of requesting initial measurements the calculated analogs of request range are used for determining the divergence of the spacecraft on-board time scale. The main sources of error in determining the calculated analogs of the spacecraft range are errors in modeling the orbits of the GLONASS spacecraft.

5. Conclusion

During the operation of a spacecraft in orbit, additional perturbations of the movement parameters of its center of mass and departure of the onboard time scale may occur, which will also distort the ephemeris-time information available on board the spacecraft, which will lead to a deterioration in the accuracy characteristics of the consumer navigation definitions. Correction of the ephemeris-time information can be carried out after the spacecraft enters the zone of visibility of radio and optical equipment ground control systems, space navigation systems with the measurements of the navigation

parameters of the spacecraft, processing them in the control center of space navigation system, the formation of the corrected ephemeris and time information, and its transfer to the board to be for included in the navigation frame. But, in the time interval from the occurrence of additional disturbances to the transfer of modified ephemeris-time information to consumers, the ephemeris-time information will be transmitted to the consumer in the navigation frame, the accuracy characteristics of which may not meet the specified requirements.

The results will be used for development and effectively use the Global Navigation Satellite System through the introduction of advanced satellite navigation technologies for the socio-economic development of the country.

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